

Throughout the 1980s, the mobile robotics community was hampered by a lack of supporting sensor technology for environmental perception and navigation, and so despite the many rosy forecasts (largely influenced by the microcomputer boom), any significant forward progress was extremely slow. Introduced in 1982, the Polaroid electrostatic sonar set off a flurry of excitement as probably the single most influential sensor breakthrough in terms of its catalytic influence on the research community, but by itself it simply wasn't enough. The advent of the much-hyped autonomous mobile robot performing useful functions around the home, office, or factory floor just didn't materialize.

Early in the market research and technology assessment required for the revised edition of *Sensors for Mobile Robots, Theory and Application* (due out next year), I was profoundly struck by the way things have begun to change. While the Polaroid sonar remains even today the mainstay of many systems, designers no longer have to rely exclusively on this versatile device for all the required functionality of a truly autonomous robot. The cost of scanning laser rangefinders is coming down for high-end applications, while for short-range needs that don't require scanning, Sharp offers a self-contained IC-size triangulation ranging system that costs only \$5.

The Intelligent Vehicle Highway Systems program sponsored by the Department of Transportation has played a major role in providing the perceived high-volume application market that simply didn't exist in robotics, spurring the development of many spinoff technologies. The results can already be seen in off-the-shelf products such as microwave and millimeter-wave radar systems for collision avoidance, Doppler-based optical and radar velocity sensors, miniature magnetometers that are smaller, cheaper, and more accurate than the fluxgate compass, and small, low-cost fiber-optic and solid-state rate gyros.

Other high-volume markets (such as laptop computers and internet accessories) have also made significant contributions, yielding low-cost miniature cameras, incredible processing power in small configurations, and more efficient batteries to supply the needed energy. Collectively these emerging technologies provide new tools to design and incorporate small, lightweight, low-power intelligent sensors that just a few years ago were decidedly impractical. SRI, for example, has developed a miniature stereo vision module consisting of a pair of circuit-board-mounted CCD cameras weighing only 3 ounces, with the required image processing handled either by a DSP, an FPGA, or a PC-104 stack, as appropriate.

But just as Polaroid gets my vote for the major contribution in the previous decade, I'd have to pick the advent of carrier-phase differential GPS as the most significant breakthrough in the 1990s. This innovative solution uses an existing multi-million dollar network of satellites installed and maintained by the Department of Defense to provide absolute global positioning accuracies down to 2 centimeters for exterior applications. As a result, the much tougher (relative to indoor) outdoor navigation problem was instantly transformed into a low-risk issue for those scenarios that enjoy minimal satellite occlusion.

Looking forward, the future seems very exciting indeed, as MEMS technology catches up to the phenomenal advances already being achieved in electronic fabrication. Sensors will continue to evolve at an exponential rate, getting smaller, lighter, and cheaper as manufacturing processes improve. The results will yield more intelligent and versatile sensor systems that are in keeping with the design restraints imposed by battery-powered mobile systems, with such promising possibilities as CMOS-camera-based vision systems, cheaper and higher-resolution FLIRs, and flash-ladar 3D imaging. The emerging field of mobile robotics should only thrive accordingly.